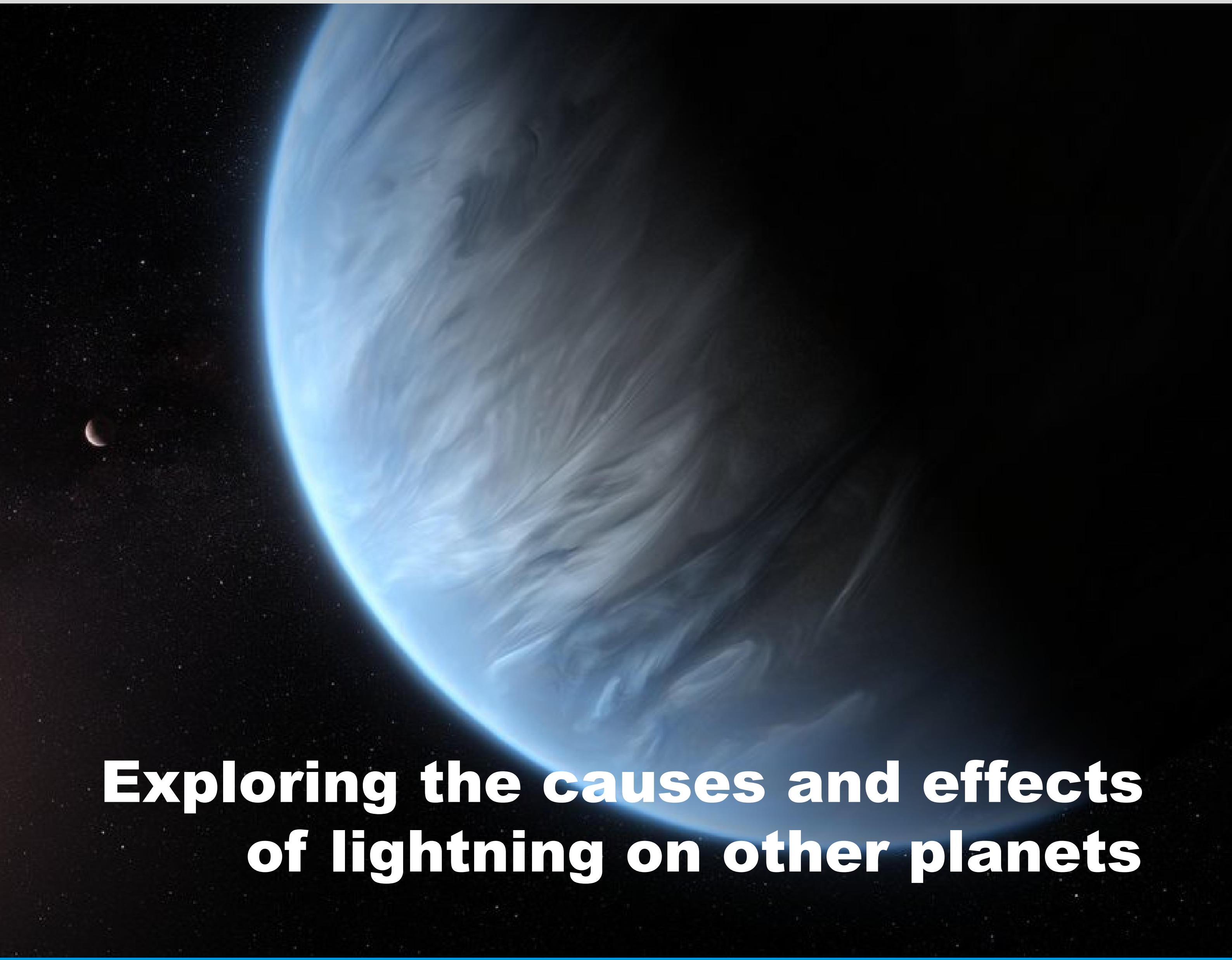
Belgium esero

CHAMELEON
Virtual Laboratories for Exoplanets and Planet-Forming Disks

LIGHTNING IN SPACE

2nd & 3rd grade secondary education
Teacher guide



Exploring the causes and effects of lightning on other planets

●●●●●●● How is lightning generated on Earth ●●●●●●●
●●●●●●● Where does lightning occur and why? ●●●●●
●●● Can you simulate lightnings in the classroom? ●●●

OVER ESERO BELGIUM

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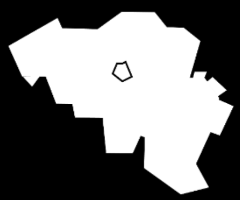

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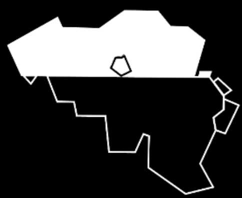

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Lightning in space

Exploring the causes and effects of lightning on other planets

Teacher guide

Fast facts

Target group	15-18 year old students.
Type	Inquiry based learning (In class student lead experiments)
Lesson time	2 x 50 minutes
Needed	▪ Polystyrene plates ▪ Aluminium foil plates ▪ Wool material
Topics	▪ Physics ▪ Space ▪ Exoplanets ▪ Lightning ▪ Electricity ▪ Inquiry learning ▪ Hands-on
Learning objectives	▪ Explain why lightning is important to exoplanet science ▪ Explain what is needed for lightning to occur ▪ Identify the variables in an experiment/demonstration ▪ Demonstrate how triboelectric charging can be used to form lightning. ▪ Use scientific methods to test and record the effects of systematically changing a variable ▪ Present your findings to the class

Summary

In this set of six activities students will use inquiry learning methods to teach about lightning on other planets, and why understanding lightning and electrical charges plays an important role in exoplanet science. Students will be guided to create their own lightning in class using hand-on experiments in groups. The students will then have the opportunity to consolidate their learning by presenting and discussing their findings to the class.

Colofon

First edition	January 2023
Updates	
Conditions of use	This resources can be used freely for education purpose. When you copy parts of it, then a correct reference has to be made to the original. The most recent version can be downloaded on www.esero.be > NL > Lesmateriaal.
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Summary of activities

① Introduction Quiz

Description: The students will be introduced to the idea of lightning in space and on other planets through the use of a true or false quiz with the class.
Outcome: Engage the students, gauge their prior knowledge and introduce new concepts.
Requirements: None.
Time: 10 minutes.

② Demonstration video

Description: A video will be shown to the class of lightning being demonstrated using household objects.
Outcome: Introduce the class to the demonstration. Illicit intrigue and questions from the class as to how it works.
Requirements: Completion of Activity 1.
Time: 5 minutes.

③ List the variables

Description: Students will work as a class to list the variables that might affect the demonstration and will begin to plan our their experiments.
Outcome: Practice of scientific methods and thinking.
Requirements: Completion of Activity 2.
Time: 5 minutes.

④ Student experiments

Description: Students are split into groups and are provided with the equipment needed to perform the demonstration. Each group is given/chooses one variable to systematically adjust and record the results of.
Outcome: Inquiry learning: using scientific methods to explore and understand how lightning occurs.
Requirements: Completion of Activity 3.
Time: 30 minutes.

Optional break

⑤ Presentations of findings

Description: Students will present the results of their experiments. They will explain the effects of changing their given variable, and share their hypothesis' about why these effects may have occurred.
Outcome: Presenting scientific results and using those results to come to informed conclusions.
Requirements: Completion of Activities 1 through 3.

Time: 20 minutes.

6 Post-activity discussion

Description: The students will apply their knowledge they have learnt about lightning to answer questions about how this information can help astronomers.
Outcome: Application of their new knowledge to different situation. This will help to both evaluate and solidify their learning.
Requirements: Completion of Activities 1 to 4.
Time: 30 minutes.

Introduction

Lightning is a fascinating physical phenomenon with many interesting effects on a planet's atmosphere and beyond. Learning about lightning can help students to understand electrical charge and electrical fields in a novel and exciting context. Learning about lightning in space can help to show students some of the applications of scientific concepts such as electric charge outside of what may be expected.

Lightning storms are common occurrences in most planetary atmospheres with clouds. As you are likely aware, lightning storms occur regularly on earth.

Figure 1: Lightning photographed by ESA astronaut Paolo Nespoli from on board the International Space Station.

Lightning also occurs on planets in our solar system aside from Earth. Lightning storms are particularly active on Jupiter and Saturn. They are also found on Uranus and, most recently, Venus. These lightning storms have been observed by space crafts such as Galileo (Jupiter) and Cassini (Saturn).

In addition to lightning that is found in our solar system, it is also predicted that many of the planets that we have found outside of our solar system (exoplanets) could also have lightning. We have discovered over 5000 exoplanets, and many of these have the right conditions for clouds to form, and astronomers are searching for chemical signatures in exoplanet atmospheres that scientists believe could be caused by lightning in those clouds.

Lightning may also be found occurring in clouds in space outside of planetary atmospheres. There are currently exoplanet scientists who are investigating the causes and effects of lightning within protoplanetary disks (the dusty disks around stars where planets form).

Background

How lightning occurs

Lightning occurs when there is a charge separation with in a cloud leading to one side of the cloud being negatively charged and the other being positively charged. When this charged side of the cloud is brought near to another conductive object (such as the ground or another cloud), the charged side of the cloud will attract the opposite charge in the conductive object and a potential difference will build up in the gap between them. When this potential difference is large enough, it can overcome the non-conductive air between the objects and discharge a high energy, high temperature stream of electrons, ionising the channel of air as it travels. This is what we see as lightning. The thunder that accompanies lightning is the sound of the air around this channel of electrons being heated so dramatically and so quickly that the expansion of the air causes a shock wave.

The charge separation in the cloud initially happens though a combination of factors and effects such as gravity, triboelectric charging and air currents. Clouds are made up of a combination of types of particles including small liquid droplets and ice crystals and larger soft hail.

During a storm, the particles in a cloud will undergo lots of turbulence causing the particles to collide frequently. This causes triboelectric charging of the particles. The small liquid droplets and ice crystals tend to lose electrons in this, resulting in them becoming positively charged and the larger hail tends to attract electrons, resulted in them becoming negatively charged. Gravity and air currents bring the larger negatively charged particles to the bottom of the cloud, and the smaller positively charged particles to the top of the cloud. This results in a cloud with two sides with a very strong charge, ready for lightning to come from them.

Triboelectric Charging

Triboelectric charging is an important part of lightning formation. Triboelectric charging is also known as ‘static charge’. You may have experiences this in everyday life, for example when taking clothes from the dryer and finding them cling together, or when you brush your hair with a plastic comb. This charging is due to the transfer of electrons from one material to another, leaving both materials with a net charge. Some materials are more likely to collect electrons, and some materials are more likely to lose electrons. Most atoms begin neutrally charged, and so have an equal number of protons and electrons, but when some materials are rubbed together electrons will be pulled from one material onto the other. This leaves the material that lost electrons with a net positive charge, and the material that gained the electrons with a net negative charge. The reason that the materials must be rubbed together for this to happen more effectively is that it allows maximum contact between the surfaces of the materials.

A list of materials ranked by their tendance to lose or collect electrons can be found by looking up the ‘Triboelectric series’. This list of materials shows the relatively tendency of a material to build up a net charge. It does not tell us the materials conductivity or the speed at which the material will lose their charge.

The effects of lightning

In order for lightning to occur, there needs to be a planetary atmosphere with some type of clouds in it. There also needs to be turbulence or wind, and particles of different materials in order to cause the triboelectric charging needed. There is a potential for direct observations of lightning flashes on other planets (in our solar system and beyond) using radio telescopes, and these observations can tell us about a planets atmosphere.

Lightning is a very high energy event in an atmosphere. The high energy and temperatures associated with a lightning flash can trigger chemical reactions that would normally not occur in the atmosphere of a planet, altering the planets atmospheric composition. This effects both the types of reactions possible on a planet, and will also effect the observations made my astronomers.

In the early stages of earths lifetime, lightning may have played a significant role in the synthesis of prebiotic molecules as first demonstrated by the Muller-Urey experiments in the 1950s. Due to this, it is not unreasonably to assume that, given the correct conditions, lightning could play a role in the origin of life on other planets.

Activity 1
Introduction to Lightning in Space

In this activity, students will be introduced to the idea of lightning in space. The goal of this activity is to gauge students prior understanding to the topic and to engage them and elicit the students interest. The science behind the lightning will not be addressed in this activity, instead it will focus on where lightning can occur, what effects it can have, and why it is important for exoplanet scientists.

Equipment

Projector/screen & Digital presentation (provided in attached PowerPoint presentation)

Exercise 1: Lightning True or False

Do not hand out the student worksheets until after the initial presentation (it has 'spoilers') Follow the slideshow of true or false questions about lightning. For each question poll the students before revealing the answer or utilise methods such as 'think, pair, share'. If there are many additional and follow up question from the students at this stage, it is suggested to write down these questions so that they can be addressed at the end of the lesson.

Discussion

Lightning in protoplanetary disks and exoplanets is an active research topic in the scientific community and astronomers are very interested in learning more about it and its effects.

As seen in the true or false questions, exoplanet researchers have not yet directly detected lightning flashes on exoplanets or in protoplanetary disks, but it is very probable that they are occurring and many astronomy researchers are focusing on making predictions for these. If lightning is observed in space, it is important to know what this scientific discovery tells us.

Throughout this set of activities, we will learn about the conditions needed for lightning to occur so that if lightning is observed in space we know what conditions must be present in those locations.

Student worksheet question?

1.1 What conditions do you think are needed to cause lightning?

It is suggested to ask this question using ‘think, pair, share’. There is no set answer for this question at this stage. The goal of this question is to peak the students inquiry. The same question will be asked later in the lesson (Activity 6) and answers will be provided.

Activity 2

Demonstrating Lightning

In this activity, the students will be shown a video of a demonstration showing lightning. They will be encouraged to question why and how this demonstration works.

https://www.youtube.com/watch?v=sk2Uu2lygUA&ab_channel=sciencemuseumok

It is important that you stop the video at 1:40 before the science behind the demonstration is explained.

Discussion

The students should see the lightning happening and it is encouraged that they question how this is happening. Answers should not be provided by the teacher at this start, the students will use their questions to help them develop hypothesis themselves and test these in activity 4.

Exercise 2 : Student worksheet Questions

The following questions are included in the worksheet to encourage students curiosity and engagement. The answers to these questions should be discussed as a class.
When the lightning flash occurs in this demonstration, there is an accompanying noise. What is the equivalent to this when lightning occurs on a planet?

Thunder. The air around the lightning flash is heated so quickly to such a high temperature that there is a shock wave that can be heard.

Activity 3
Determining the Variables

In this activity, students will work as a class to determine the variables in this demonstration.

Equipment

A whiteboard/black board/ screen that all of the students can see

Exercise 3

As a class, ask the students which variables are present in this demonstration. Theses should be written up on a board or screen that all of the students can see. The teacher may guide the students as needed. It is suggested to use 'think, pair, share', or similar, for this activity.

Results

With guidance from the teacher where necessary, the following variables should be identified by the class. The variables in bold are suggested to be tested in the next activity, so identification of these is highly recommended. The variables not in bold are useful for context and completeness and the identification of these will aide in class discussion. You class may also identify other variables that are not on this list! Not all variables will have a direct parallel to exoplanet atmospheres. This is because all physical analogies and demonstrations will have limitations, as it is not an exact replica of an exoplanet atmosphere.

Variable In Experiment	Parallel in Exoplanet Atmosphere
The time/amount of strokes that the items are rubbed together	The turbulence/rubbing together of particles in clouds
The material of the probe being brought in to discharge the plate	The composition of the planet surface/clouds on the exoplanet
The shape of the probe	The structure of the planet surface/clouds
The material of the plates/containers/other components	The chemical composition of the exoplanet clouds
Air humidity	Air humidity on the exoplanet
Atmospheric pressure	Atmospheric pressure on the exoplanet
Atmospheric temperature	Air temperature on the exoplanet

Activity 4

Exploration/Experimentation

In this activity, students will be split into groups and asked to investigate the effect of one variable per group.

Equipment per group

- A piece of wool material
- Polystyrene plate/ lid of a polystyrene container
- Pencil with an eraser on the end
- Thumb tack
- Aluminum foil plate/dish
- Metal fork
- Plastic fork (optional)

Health and safety

This demonstration involves static shocks. These are small enough discharges that they do not hurt and are likely to cause no damage to and surroundings. However, in the interest of caution it is advised to remove flammable items from the vicinity of the experiment, and to not have electronics too close to the experiment as if the discharge goes directly to an electronic it has potential to damage the electronics.

Exercise 4

The students should be split into groups of 2 or 3 for this activity. Each group will be asked to choose a variable to test. If they have difficulty selecting a variable you may allocate them one of the following suggested variables:

1 The number of times the plate is rubbed with the wool
2 The material of the probe
3 The shape of the probe

The optimum combination of variables is:

- Rubbing the plate as many times as possible (this will plateau at a certain number as the charge in the plate is limited by the number of electrons in the wool and the plate initially. This number will also be affected by the humidity as in higher humidity the charge will dissipate quicker than in dry conditions)
- A metal or other conductive material as a probe
- A pointed end to the probe

When a group is changing one of the variables, it should be suggested that the group keep the other control variables at the optimum values stated above.

Suggested timing

This activity has 30 minutes allotted in the schedule.

It is suggested to give the students approximately 15 minutes to work on experiment uninterrupted. After this initial 15 minutes, some groups may have produced lightning and some groups may not have. It is suggested that at this point groups who were successful can assist groups that have not yet produced lightning.

Ideally, by the end of the 30 minutes the majority of the groups will have seen lightning either in their group, or in another groups experiment. During this activity it is important to emphasise to the students that experiments will not always go as planned, and that this is part of the nature of science.

Nature of Science

During this lesson it is beneficial to emphasise to students that they are conducting scientific experiments, and scientific experiments not always go as planned. An important part of scientific practices is documenting which experiments do not work, and hypothesising why they may not be working as this is all part of the process.

Experiments to do with electromagnetism such as this experiment can also be notoriously unreliable because they depend greatly on factors such as the exact materials used, the timing of actions, the humidity in the room, and the materials that are surrounding the experiment and more

Results

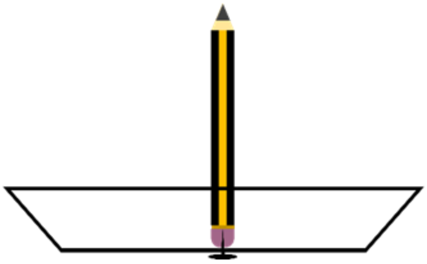
Students can record their results in any way they see fit. The clearest result will be if students can hear/see a lightning flash or not. Students can note down if the flash was visible to the human eye. They may also note down how loud accompanying noise was. As this is subjective, it is useful to have multiple people viewing and recording this information. If a group finishes testing their initial variable, they may experiment further by exploring a second variable or changing the variable in smaller increments.

Discussion

In this activity students are encouraged to think independently and practice their problem solving skills. Students are allows to come up with their own hypothesis' and test them using methods that they deem appropriate and helpful. It is important during this activity that the students are documenting their results in an appropriate and accurate manner.

Demonstration Instructions

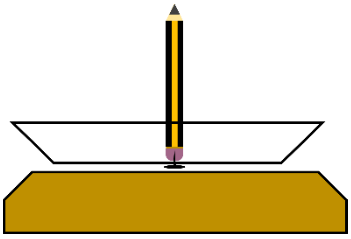
Step 1
Pierce a thumb tack through the bottom of the aluminium foil tray. Push the eraser on the end of a pencil onto the thumb tack. The pencil will now act as a handle and allow you to lift the tray up without touching it. Place this aside for now.



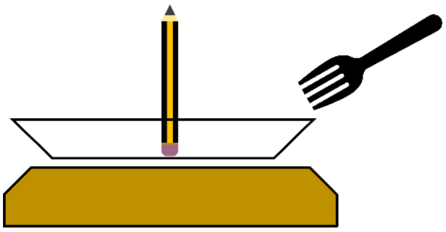
Step 2
Rub a dry piece of wool against the bottom of a polystyrene tray for two minutes. A little pressure can be applied, but not hard enough to break the container. Once the tray is charged enough, it should lift up when the wool is lifted.
It may help to wear rubber gloves for this stage of the experiment to minimise the grounding of charge through your body.

Step 3
Set the piece of wool aside and leave the tray, upside down, on the table. Do not touch the top of the tray.

Step 4
Using the pencil to lift it, place the aluminium foil tray on top of the polystyrene tray.



Step 5
Slowly bring a metal fork towards the rim of the aluminium tray. Once it is close enough, if you watch carefully you might see a flash of lightning between the prong of the fork and the rim of the tray. You may also hear a small 'cracking' noise from the electrical discharge. This is analogous to the thunder that accompanies lightning.



Tip
The static can be removed from the polystyrene tray by rubbing your hand or a damp cloth over it a few times. Ensure to dry the polystyrene tray thoroughly before restarting the experiment.
It is also very important to ground both the probe and the foil tray before restarting the experiment. This can be done by holding them in your hand (assuming you are not wearing thick soled trainers), or placing them against a metal table leg or something similar).
Ensure that there are at least a few layers of wool material between your hand and the tray when rubbing them together. You may also choose to try using rubber gloves for this step.

Activity 5
Group Presentations

In this activity, students will present their findings from Activity 4. These findings will be used to determine what variables are needed for lightning to occur in this experiment, and therefore in space.

Equipment

A whiteboard/black board/ screen that all of the students can see.

Exercise 5

The groups of students will take turns to present their findings to the rest of the class. This can be done in a manner seen fit by the teacher (eg. Oral presentation, digital presentation, poster etc.)
The students should be encouraged to clearly present the following points:

- The variable they were testing
- Their hypothesis before testing began
- What they found during their testing
- Was their hypothesis confirmed or denied
- After seeing the results of the test, why they think changing their variable had the effect that it did.

Discussion

You may wish to write brief notes from each group up on the board.
After the students have presented their findings, a discussion can be had as a class to determine what they have found out collectively and try to come up with a list of the conditions needed for lightning on a planet.
Students will then be asked to write a short paragraph describing their findings in order to summarise what has been found.

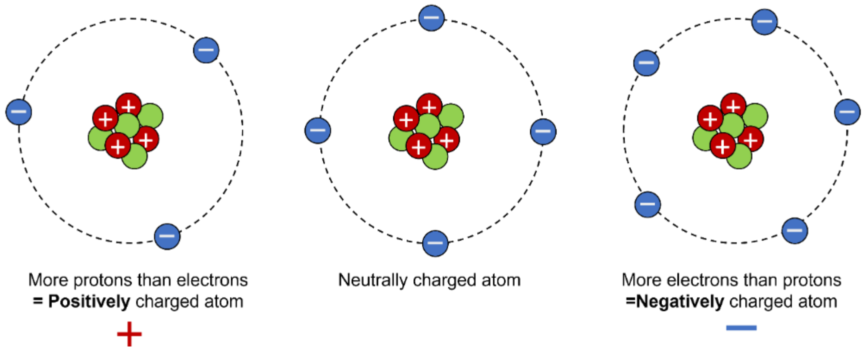
Activity 6

Post-activity Discussion

In this activity, students will map out the transfer of charge in the demonstration and then apply this to the transfer of charge in lightning formation. They will use the knowledge acquired throughout this lesson and use it to justify the importance of understanding lightning to exoplanet scientists.

Some background on charge transfer

All objects are made up of atoms. Atoms are made up of: Protons (positively charged), electrons (negatively charged) and neutrons (neutrally charged). Usually an atom will have the same number of protons and electrons. But sometimes electrons can be removed from, or added to an atom. If an atom loses an electron, it will then have more protons than electrons and become positively charged. If an atom gains an electron, it will have more electrons than protons, and therefore become negatively charged.



Triboelectric Charging

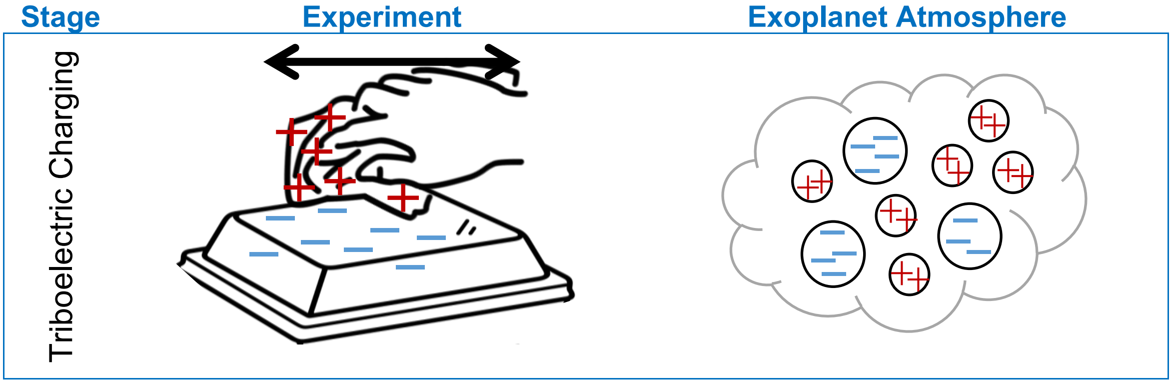
Triboelectric charging is a type of contact electrification that occurs when certain materials are rubbed together and charge is transferred from one to the other. You might have experienced this when taking clothes out of the dryer, or combing your hair. This transfer happens because the atoms in some type of materials tend to attract electrons to them, and the atom in other materials tend to give up electrons easily, so when they are rubbed together the particles come into close and frequent contact and the electrons will move between them.

Exercise 6

This set of questions asks students to map the movement of charge within both the experiment and within clouds. The following diagrams show the movement of charge. These questions should be attempted by the students in groups, discussion between students is encouraged. After each section, you may wish to go through the answers together on the board. It may be helpful to have each group come up and draw one part of the answer on the board themselves.

6.1 Triboelectric Charging

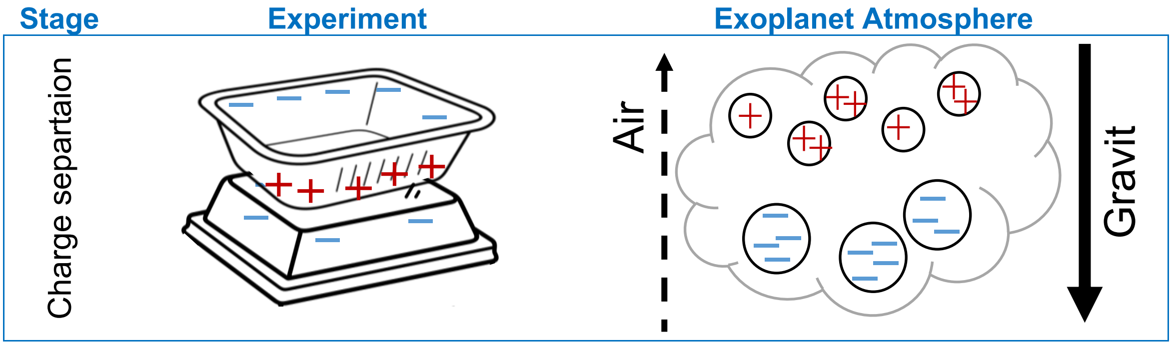
Wool tends to give up electrons, polystyrene tends to collect electrons.
Small ice crystals tend to give up electrons, Large hail particles tend to collect electrons.
When rubbed together charge will transfer from one object to the other.



6.2 Separation of Charge

Experiment:
The charges in the metal tray will move because metal is a conductor.
The charges in the polystyrene tray will stay where they are because plastic is an insulator.
The positive charges in the metal tray will be attracted to the negative charge in the polystyrene tray, the negative charge in the metal tray will be repelled. The top of the metal tray now has a large negative charge.

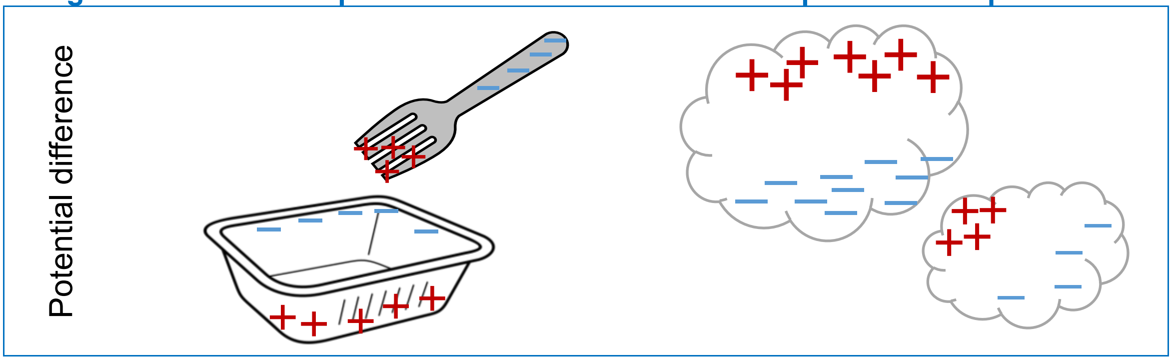
Exoplanet Clouds:
The air currents will blow the particles up (away from the centre of the exoplanet). Gravity will pull the particles down towards the centre of the exoplanet.
The lighter particles will be less effected by gravity than the heavy particles and the heavy particles will be less effected by the air currents. This results in the top of the cloud being positively charged and the bottom of the cloud being negatively charged.



6.3 Potential Difference

The external objects that are brought in are conductive, so the charge will move freely in them.
The opposite charges are attracted to each other, and like charges are repelled.

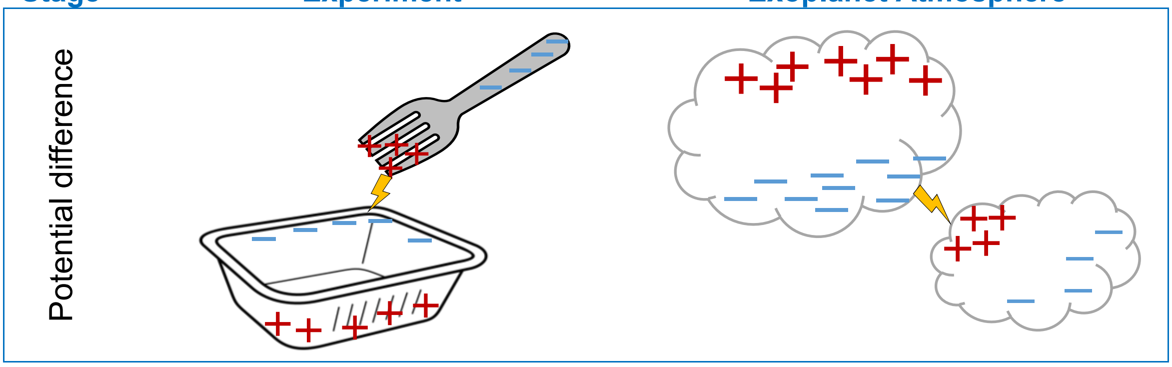
Stage Experiment Exoplanet Atmosphere



6.4 Lightning Occurrence

Lightning will occur at the closest point between the objects.

Stage Experiment Exoplanet Atmosphere



Exercise 6.5

Q1
Imagine you hear in the news that astronomers have found evidence of lightning on an exoplanet. From this information, what can you predict/deduce about the planet in question? Give as much detail as possible.

If an exoplanet has lightning occurring on it then this means that the conditions for lightning to occur must be met. This means that the planet must have:

- *An atmosphere*
- *Clouds with different sized particles in it*
- *Air currents/turbulence in the air*
- *An atmosphere that is semi conductive*

Q2

If you were on another planet where clouds all had particles that were exactly the same size and made of the same materials, would you expect there to be more or less lightning than if the particles were different sizes and materials? Explain your reasoning.

If an exoplanet has particles that are all the same size and material then there will be no charge transfer then they are rubbed together through cloud turbulence. This means that clouds will not have a charge separation and so a large enough potential difference will not form for lightning to occur.

Links

ESA resources

ESERO Belgium: classroom resources, teachers trainings and STEM projects for schools: www.esero.be
Teach with Exoplanets: https://www.esa.int/Education/Teach_with_Exoplanets
ESA classroom resources: www.esa.int/Education/Classroom_resources
ESA Kids homepage: www.esa.int/kids

Extra information
Chameleon Innovative Training Network https://chameleon.iwf.oeaw.ac.at/

Annex 1

Lightning True of False Questions

A slideshow with all of these questions in can be found in the attached PowerPoint presentation

1. Lightning has only been observed on Earth
   - False!
   - Lightning storms occur on Jupiter, Saturn and Uranus and Venus. Many of these lightning storms have been observed using spacecraft passing by these planets
2. Lightning has only been observed in our solar system
   - True (for now).
   - Lightning has been predicted on planets outside of our solar system (exoplanets) but scientists are still working on confirmation.
3. Lightning can only occur in the atmosphere around a planet
   - False! (We think).
   - There are currently exoplanet researchers looking at lightning that is expected to occur in protoplanetary disks. These are disks of gas and dust that orbit stars and are where new planets are formed..
4. Lightning can change the chemical composition of a planet's atmosphere
   - True!
   - Lightning flashes are incredibly high energy. This energy can heat up the atmosphere very quickly and to a very high temperature. This heating of parts of the atmosphere can trigger chemical reactions that would not otherwise occur.
5. Lightning can play a role in the beginning of life on a planet
   - True (we think)!
   - On the Early Earth it is believed that lightning may have played an important role in the synthesis of prebiotic molecules. This was first demonstrated by the Miller-Urey experiments the 1950’s. This means that, given the correct conditions, lightning could potentially play a role in the origin of light on other planets

Annex 2
Mapping the demo to real life lightning

Demonstration	Component reasoning	Analogy in lightning
Polystyrene plate	Polystyrene attract electrons so will build up a negative charge when in contact with a material that gives up electrons. The polystyrene plate is a solid non-conductive material. This means that both the particles and the charge cannot move within the polystyrene plate.	The polystyrene plate holds negative charge which helps to create the charge separation necessary for lightning. The details of this are explained in the row 'Placing the foil plate ontop of the charged polystyrene plate'
Rubbing wool on the polystyrene plate	The collision of particles of different sizes, densities and composition causes a transfer of charge between them.	The rubbing of the wool against the plated demonstrates the tranfer of charge as two different materials rub against each other, like the hail and ice crystals in a cloud. The more the materials rub against each other, the larger the build up of charge will get.
Foil plate	Aluminium foil is a conductor so the charge within the foil plate is free to move with in the plate.	*Foil plate = Cloud* Clouds are made up of gas, small liquid droplets and ice. All of these can move freely within the cloud, and so also charge can travel freely within the cloud
Placing the foil plate on top of the charged polystyrene plate	The charged polystyrene plate, when held against the foil plate, creates a charge separation in the foil plate. The negatively charged polystyrene plate attracts the positive charges in the foil plate towards it, and the negative charges away from it.	This forced charge separation is an analogy for gravity and other physical effects causing a charge separation in a cloud. In a cloud, gravity will cause larger (negatively charged) dense soft hail to settle to the bottom of a cloud, and air updrafts will cause small (positively charged) water droplets and ice crystals to move upwards.

Probe (eg. Metal fork.)	The probe is neutrally charges but is conductive. This means then when brought close to a negatively charged object, the electrons in the probe will be repelled to the further end of the probe. This results in the end of the probe closest to the negatively charged object being positively charged, resulting in a charge separation between the two objects.	The probe in the demonstration represents the ground, an object on the ground, or (more commonly) another cloud. When the negatively charged underside of the cloud is close to another object that charge can flow freely in, the electrons are repelled in the object and this forms a charge separation between the initial cloud and the other object.
The spark between the plate and the probe	The charge build up across the separation is large enough that the electrons can form a channel through the air to get to the probe.	This discharge seen in this demonstration is the same effect as lightning
The associated noise	There is a small crackling noise as the electricity discharges. This is due to the air being very quickly heated to extreme temperatures around the channel of electrons. This heating causes the air to expand so fast that it causes a shock wave	This way this sound is produced is the same way that thunder is made.